SECOND SEMI-ANNUAL PROGRESS REPORT

OF

HEAT TRANSFER AND INSTABILITY STUDIES OF TWO-PHASE FLOW

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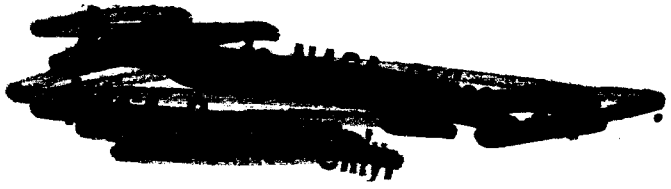

Introduction

This report covers the work accomplished during the six-month period ending 31 August 1965. The period considered herein is that period during which all required preparatory negotiations and arrangements have been completed prior to engagement into the actual research program. The negotiation with the University Officials concerning the renovation of the laboratory area, the budgetary transfer necessary to accomplish the research plan, and the detailed design and plan for the immediate research problems were of primary importance and have been successfully attained. Our appreciation is extended to the University officials who have given us the priority to use and renovate the laboratory area and to NASA Headquarters and NASA Lewis Research Center who approved our request of the budgetary transfer.

The first report concerning the mass transfer effect on two-phase hydrodynamic instability will be released as a NASA Technical Note or Contractor Report in October, 1965.

Background Information

On March 1-3, Drs. R. P. Harrington and Haruo Oguro attended the NASA-University Program Review Conference held in Kansas City, Missouri. The main object of this trip was to explore the possibility of participating further in the NASA program and to evaluate our participation in this program in relation to other universities.

Dr. Robert W. Graham, Head, Experimental Section, Fundamental Heat Transfer Branch, NASA Lewis Research Center, was invited to give a Departmental Colloquium Lecture entitled, "Problems of Two-Phase Flow" on April 15. Dr. Graham's lecture was closely related to the present two-phase flow research project and brought significant response from the Department staff and students.

The re-arrangement of the budgetary distribution was discussed extensively during the first semi-annual period. The petition for the transfer of part of the expenditures of the salaries fund to the equipment fund was submitted to NASA Headquarters on April 29 and approved on August 4, 1965.

On August 25, 1965, Drs. Oguro and R. G. Dale visited Dr. Graham's office at NASA Lewis Research Center to present and discuss our present problems under the NASA Research Grant. Four members from the staff of the Experimental Section and Development Section joined our discussion. These discussions enabled us to exchange information and to make suggestions on our overall plans.

Renovation of Laboratory Area

Dr. R. C. Dale has been in charge of the renovation of the laboratory area. This project will be completed before the end of October, 1965.

In June, 1965, University officials approved the spending of $10,000 on the renovation of the laboratory area. The actual construction is expected to start within a few weeks. The space available for the laboratory is in excess of 2000 sq. ft. In addition, an office space of 300 sq. ft., equipped with air conditioning, will be located at one corner in order to supply adequate space for planning, discussion and storage. All necessary electrical power, city gas supply, 100 psia air source, water supply and associated equipment will be available.

Theoretical Progress

One of the important efforts in our theoretical investigation has been aimed toward the investigation of the mass transfer effect on two-phase flow. The first problem attacked was the investigation of the mass transfer effect on Taylor instability which is closely related to pool boiling instability. The viscous and surface tension effects were investigated by R. Bellmann and R. H. Pennington (1). However, there has not been any solid understanding of the mass transfer effect. Dr. Oguro and Mr. I-Wu Shen have approached this problem by assuming a non-viscous, incompressible fluid. The results will be released as a NASA Technical Note or Contractor Report in October, 1965. The report will be entitled "Mass Transfer Effects on Taylor Instability in Two-Phase Pool Boiling" by Haruo Oguro and I-Wu Shen. One of the important results may be the appearance of the exponential term in the expression of the disturbed motion which seems to be a characteristic of the mass transfer effect. The surface tension effect will be discussed briefly as a first approximation toward improvement of the present result.

Although the report mentioned above treats the fluids as incompressible, a more realistic approach should include the assumption of the compressible fluid. To approach this goal, the transient process in the vapor side has been investigated in the case of the time variable heat transfer rate on the heating surface. The analytical solution for the general case was found difficult; however, under the proper similarity concept which had been demonstrated in the theory of turbulence, a type of similar solution was possible (2). This similarity solution corresponds to the case with constant heat transfer rate on the heating surface which is the case of electrical resistance heating. To complete this problem, one difficulty is finding the "integral relation" to obtain an analytical expression for the similarity solution. Even though the analytical form of the solution is difficult to find, it is possible to find an approximate solution which is a perturbation representing a departure from the exact solution satisfying boundary conditions (3).

During the next period, an effort to obtain an approximate solution will be attempted. When such a solution is available, the results will be applicable to the generalization of the mass transfer effect on Taylor instability.

The extension of the present results of the mass transfer effect into the forced convection case will be attempted during the next period (4). Also, an attempt will be initiated using the technique generalized by Sedov (5) to obtain a general set of equations which may be applicable to the general two-phase flow. A study of non-equilibrium thermodynamics has been initiated and will be continued. A study on the effect of space charge on bubble dynamics has been initiated on the basis of electrohydrodynamics (6) (7).

Experimental Progress

Most efforts in the past six-month period have been devoted toward the completion of the design and arrangement of the experimental facility. The results were brought to the Lewis Research Center for discussion on August 25, 1965. Three blue-line prints of the assembly drawings were left there for reference.

The design of the apparatus for the pool boiling experiments has been completed and the construction is in progress. The vacuum chamber which encases the main body of the apparatus is 18 inches square and 24 inches high with 7 5/8" x 2 5/8" rectangular glass windows in each side wall. The purpose of the evacuated encasement is first, to protect people from any danger during the operation; second, to reduce the heat loss from the apparatus due to free convection and to ease the arrangement for an electrical powerline, electrical lead, and pressure line; and third, to make clear the optical path for observation.

The main body of the pool boiling apparatus is 12 inch square and 14 inch high with a double glass window in each side wall. The double glass window was designed to protect the high temperature resistant Vycor inner glass from mechanical damage by maintaining a small pressure differential across it, independent of the testing pressure.

The details of the construction of the pool boiling apparatus will be reported during the fourth semi-annual period of the present research project. In the forthcoming report, the first results of a pool boiling experiment will be included. The initial attempt at using the pool boiling apparatus will be a separation of the heat transfer due to the nucleate boiling from the heat transfer due to free convection. The screen technique, with variable mesh sizes, will be used for this purpose. Three independent transversing mechanisms to accomodate necessary sensing elements and screens were designed and their fabrication is in progress.

For the purpose of investigating the nucleation process and bubble formation in the fluid, and the bubble dynamics with interaction on each other, the effort to use a Laser technique has been initiated. Although it is too early to report any progress, one undergraduate student has started work for his thesis by exploring this technique. When we are able to demonstrate the usefulness of the Laser project, it will be added to the present two-phase flow project. It may be necessary to require additional funds in order to perform a full scale investigation. It is hoped that NASA or NSF would support the Laser project.

The design of the apparatus for the forced convection experiment is completed and the construction will begin in the near future. The main emphasis has been placed on the channel flow interaction with bubbles. The flow control section was designed to give a uniform flow at the entrance to the test section. Special care was taken to maintain the entering flow free of fluctuation. The flow channel of the test section is 4 in. wide, 1/2 in. high and 54 in. long. The frame size is 7 inches by 8 inches and 56 inches long made of stainless steel with the four pairs of double glass windows for optical observation. The principles used in the design of the windows were similar to the principles used in the design of pool boiling apparatus.

The details of the construction of the forced convection apparatus will be reported during the fourth semi-annual period. In the forthcoming report, the first results of the forced convection experiment will be included. The first attempt at using the forced loop will be to examine the effect of the small disturbance frequency on the Reynolds number which is defined at the onset position of bubble removal. The ribbon technique, which is used in the investigation of the hydrodynamic instability, will be applied.

With the approval of the budgetary transfer, we are in a position to pursue the experimental program actively during the next period. The purchase of the instruments necessary to operate the apparatus will be ordered according to schedule.

Research Personnel

Dr. Haruo Oguro, Associate Professor of Aerospace Engineering, has served as the principal investigator on a full-time basis. Dr. R. G. Dale, Assistant Professor of Aerospace Engineering, allocates 10% of his time to the project and is in charge of the renovation project. Mr. I-Wu (Peter) Shen has worked 60% of his time after June, 1965. Mr. Shu-Jen (Edward) Hsia has worked at a full-time basis after June, 1965. Both Messers Hsia and Shen were graduated and awarded Master of Science degrees from the Department of Aerospace Engineering in June and August, 1965, respectively.

Mr. Kenneth Token has resumed his work on the two-phase flow project on a full-time basis since the end of August, 1965. Mr. Barry Hannah will be joining us at the end of September, 1965. Messrs. Token, Hsia, Hannah and Shen will be Ph.D. students beginning this September.

Dr. R. P. Harrington, Director of the Institute of Space Sciences and Professor and Head of the Department of Aerospace Engineering, has served on the project on the overall matter of project planning and has constantly encouraged us.

Mr. Cupito worked about 50% of his time as a mechanic on the project. There is a definite need for increasing our fabrication capacity. Several arrangements will be made in this direction.

References

(1) Bellman, R. and R. H. Pennington, "Effects of Surface Tension and Viscosity on Taylor Instability", Quart. Appl. Math., 12, 151, (1954).

(2) Batchelor, G. K., "The Theory of Homogeneous Turbulence", Cambridge University Press, 1953.

(3) Bellman, R., "Purturbation Techniques in Mathematics, Physics, and Engineering", Holt, Rinehart and Winston, Inc., 1964.

(4) Tippets, F. E., "Critical Heat Flux and Flow Pattern Characteristics of High Pressure Boiling Water in Forced Convection", GEAP-3766, Atomic Power Equip. Dept., General Electric Co., San Jose, Calif., 1962.

(5) Sedov, L. I., "Introduction to the Mechanics of a Continuous Medium", Addison-Wesley Publ. Co., Inc., 1965.

(6) Stuetzer, O. M., "Magnetohydrodynamics and Electrodynamics", Phys. of Fluids, 5, 534 (1962).

(7) Stuetzer, O. M., "Gas Bubbles in Charged Liquid", J. Appl. Phys., 34, 958, (1963).